

# **Astrophysics Subcommittee Meeting Summary Report**

**March 17+18, 2015**

**Scott Gaudi  
(Astrophysics Subcommittee Chair)**

# NAC Astrophysics

# Subcommittee Membership

- |                                    |                                       |
|------------------------------------|---------------------------------------|
| • Dr. B. Scott Gaudi (Chair)       | The Ohio State University             |
| • Hashima Hasan (Exec. Secretary)  | NASA Headquarters                     |
| • Nathalie Batalha                 | NASA Ames Research Center             |
| • Marshall Bautz                   | Massachusetts Institute of Technology |
| • Jamie Bock (PhysPAG EC Chair)    | California Institute of Technology    |
| • Alan Boss (ExoPAG EC Chair)      | Carnegie Institution                  |
| • Patricia Boyd                    | NASA Goddard Space Flight Center      |
| • Joel Bregman (Deputy Chair)      | University of Michigan                |
| • Neil J. Cornish                  | Montana State University              |
| • Giovanni Fazio                   | Harvard-Smithsonian CfA               |
| • Fiona Harrison                   | California Institute of Technology    |
| • Jason Kalirai                    | Space Telescope Science Institute     |
| • Chryssa Kouveliotou              | NASA Marshall Space Flight Center     |
| • Kenneth Sembach (COPAG EC Chair) | Space Telescope Science Institute     |
| • Rachel Sommerville               | Rutgers University                    |
| • Yun Wang                         | California Institute of Technology    |

# **Updates from Missions.**

- **JWST**
- **Balloon program update.**
- **NICER**

# **Final Mission Study Reports.**

- **WFIRST-AFTA**
  - See report from Neil Gehrels.
- **Probe-class direct imaging missions**
  - Exo-C
  - Exo-S

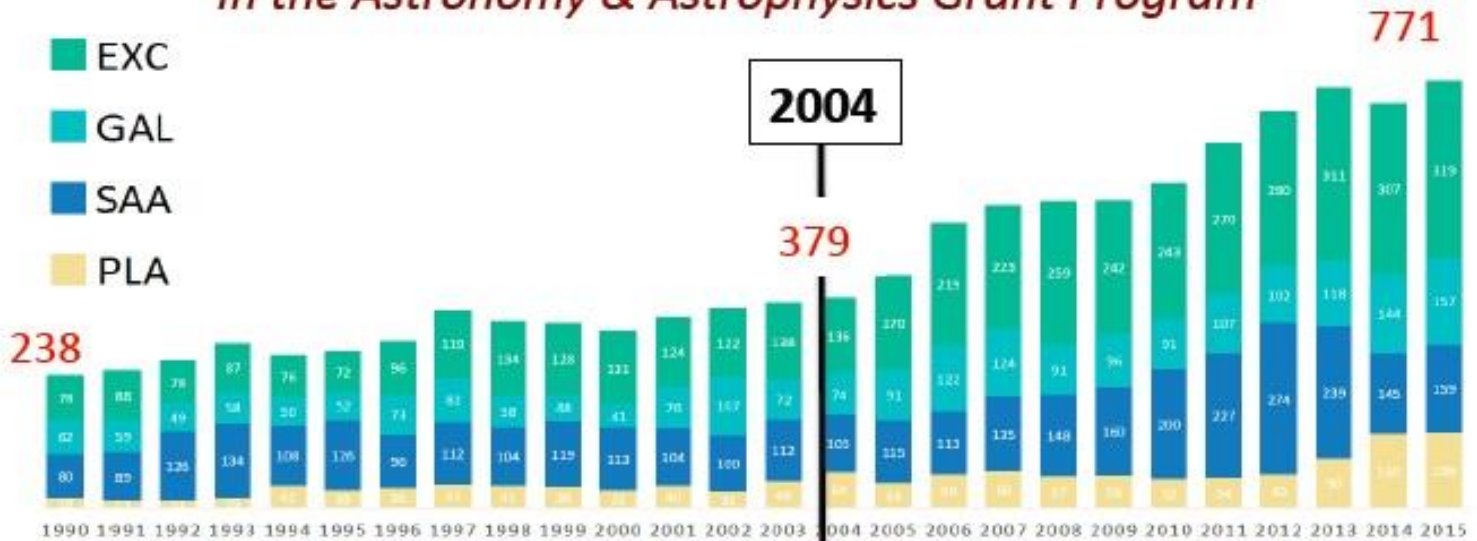
# Miscellaneous.

- The APS concurs with the JSTAC that the proprietary period for the JWST GO program should be a default of 6 months (Eric Smith)
- Interim report from the AAAC Proposal Pressures Study Group (Priscilla Cushman)
  - No clear, single, attributable cause of decreased funding rates.
- Report from Planck (Charles Lawrence)
  - A “simple” 6-parameter  $\Lambda$ CDM model still fits the Planck data extremely well!
  - No evidence for additional physics.
  - Some (minor?) tensions.

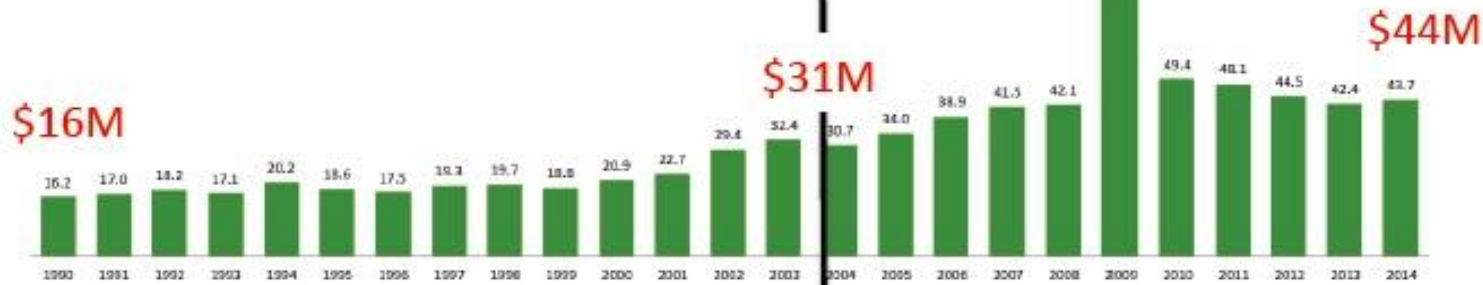
# Proposal Pressure in NSF/AST

## *In the Astronomy & Astrophysics Grant Program*

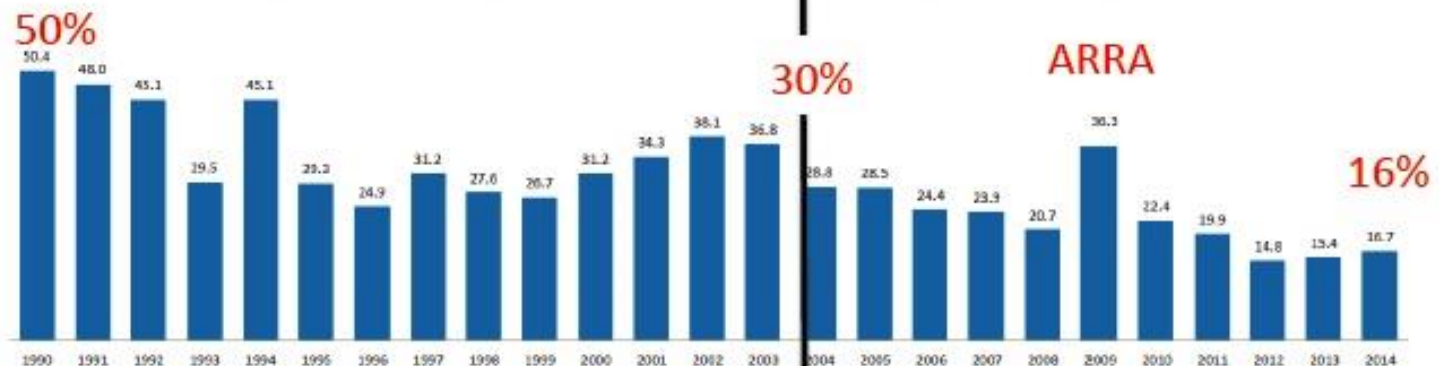
Number of AAG Proposals by program and year



AAG Budget \$M



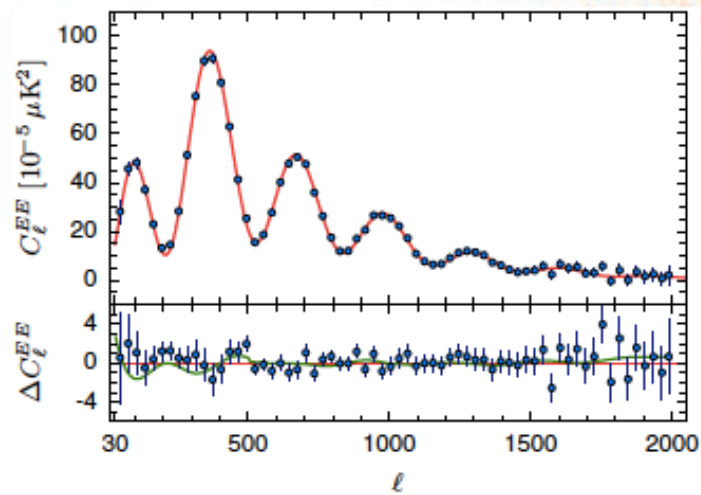
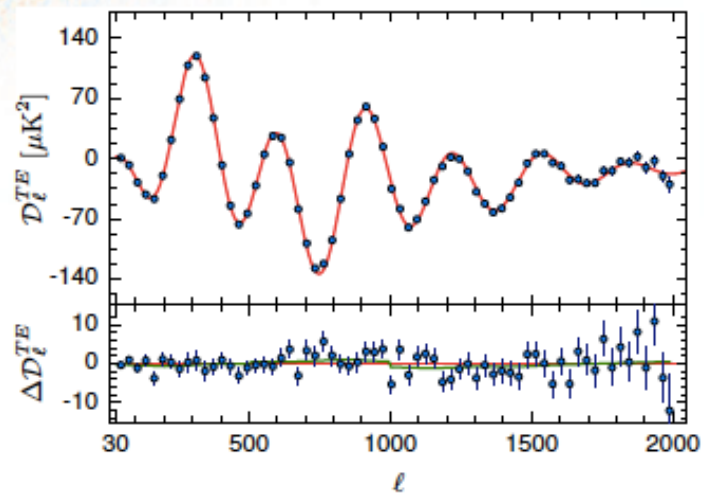
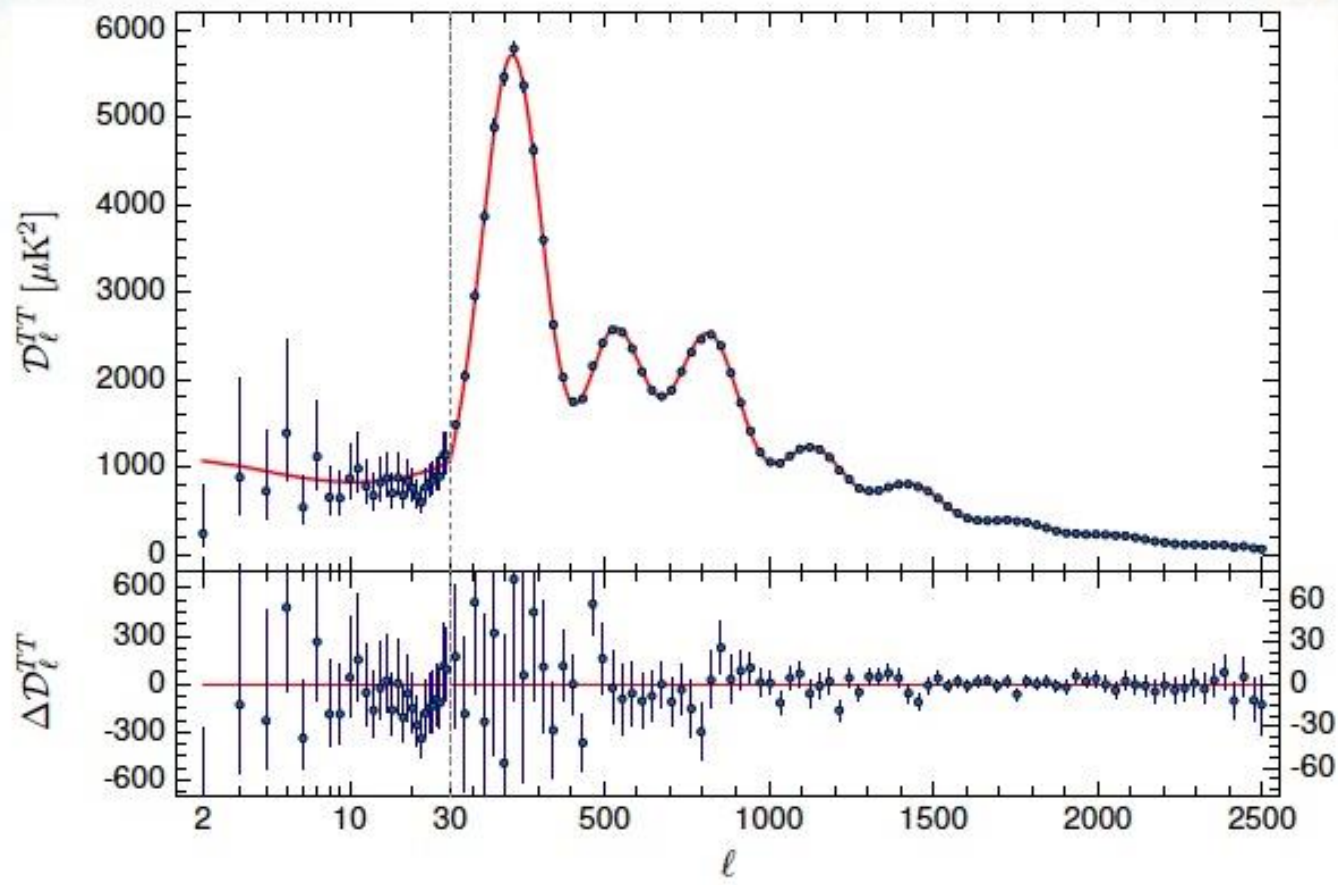
AAG Proposal Success Rate



## Summary of Demographics

*Only collected for NSF and NASA*

- The number of proposers is going up, not just the number of proposals.  
Multiple proposals from the same PI is mostly not a driver
- The rise in the number of proposers is not coming disproportionately from new assistant professors or research scientists or from non-traditional institutions
- They do not represent a shift in gender or race
- The merit category that is being depleted has a rating of VG  
Very Good proposals are not being funded
- Unsuccessful proposals are being resubmitted at a higher rate





# Just Six Numbers.

- 1 Density of baryonic matter in the Universe  $\Omega_b h^2$
- 2 Density of cold dark matter in the Universe  $\Omega_c h^2$
- 3 Angle subtended by the distance sound travelled in the first 370,000 years after the Big Bang  $\theta_{MC}$
- 4 Fraction of CMB photons scattered on their 13.8 billion year journey by electrons and protons (hydrogen) reionized by stars, quasars, etc.  $\tau$
- 5 Amplitude of the initial fluctuation spectrum  $A_s$
- 6 Slope of the initial fluctuation spectrum  $n_s$

# Just Six Numbers.

Parameter	$TT, TE, EE + \text{lowP} + \text{lensing} + \text{ext}$	$N_\sigma$
$\Omega_b h^2 [18.79 \text{ yg m}^{-3}] \dots\dots\dots$	$0.02230 \pm 0.00014$	159
$\Omega_c h^2 [18.79 \text{ yg m}^{-3}] \dots\dots\dots$	$0.1188 \pm 0.0010$	119
$100\theta_{\text{MC}} \dots\dots\dots$	$1.04093 \pm 0.00030$	3470
$\tau \dots\dots\dots$	$0.066 \pm 0.012$	5.5
$\ln(10^{10} A_s) \dots\dots\dots$	$3.064 \pm 0.023$	133
$n_s \dots\dots\dots$	$0.9667 \pm 0.0040$	242
$H_0 [\text{km s}^{-1} \text{ Mpc}^{-1}] \dots\dots\dots$	$67.74 \pm 0.46$	147
$\Omega_m \dots\dots\dots$	$0.3089 \pm 0.0062$	50
$z_{\text{reionization}} \dots\dots\dots$	$8.8 \pm 1.2$	7
$z_{\text{recombination}} \dots\dots\dots$	$1089.90 \pm 0.23$	4740
Age[Gyr].....	$13.799 \pm 0.021$	657



# Exo-S Final Report Presentation to NASA APS

Aki Roberge  
on behalf of the  
Exo-S Team  
March 18, 2015



Exoplanet Exploration Program

# Exo-S Team Members

## STDT

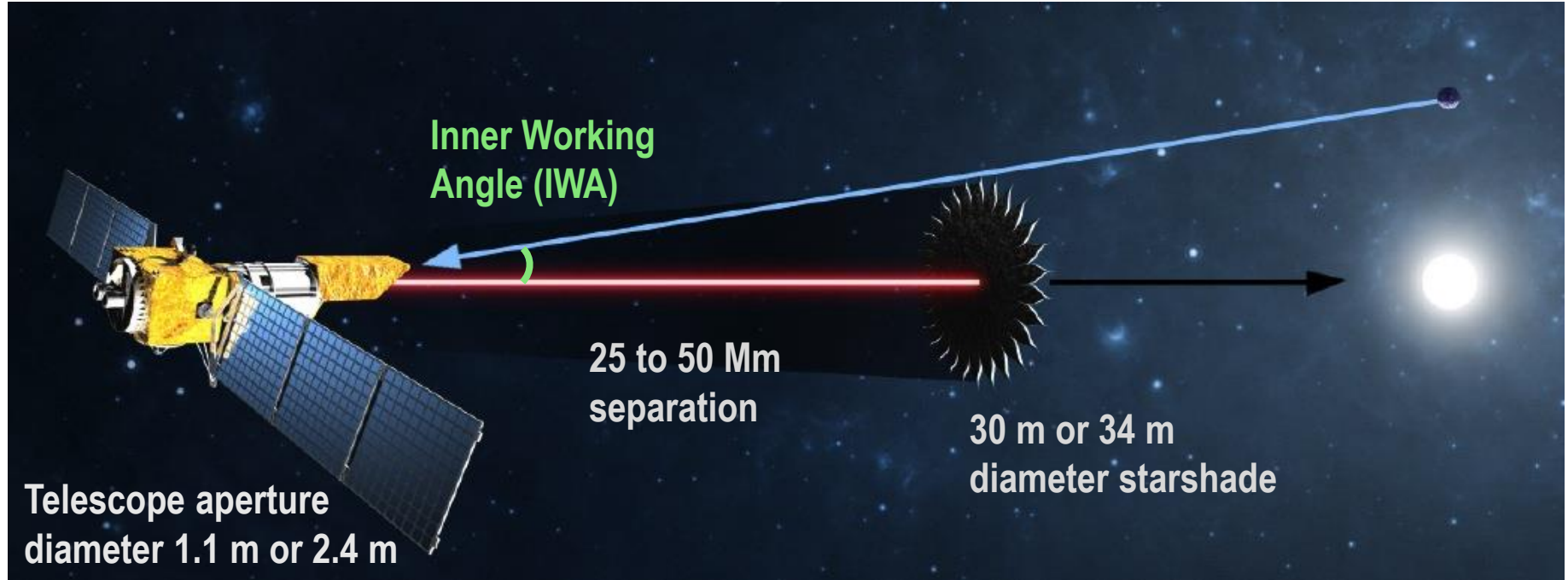
**S. Seager, Chair (MIT)**  
**M. Thomson (NASA-JPL)**  
**M. Turnbull (GSI)**  
**W. Sparks (STScI)**  
**S. Shaklan (NASA-JPL)**  
**A. Roberge (NASA-GSFC)**  
**M. Kuchner (NASA-GSFC)**  
**N. J. Kasdin (Princeton)**  
**S. Domagal-Goldman (NASA- GSFC)**  
**W. Cash (Colorado)**

## JPL Design Team

**K. Warfield, Lead**  
D. Lisman  
C. Heneghan  
S. Martin  
D. Scharf  
R. Trabert  
D. Webb  
E. Cady  
R. Baran  
P. Zarifian  
S. Krach  
B. Hirsch

# **Exo-S Study Charter**

- **Exo-S was an 18-month NASA HQ-funded study of a starshade and telescope “probe” space mission**
  - **Total mission cost targeted at \$1B (FY15 dollars)**
  - **Technical readiness: TRL-5 by end of Phase A, TRL-6 by end of Phase B**
  - **New start in 2017**
  - **Compelling science must be beyond the expected ground capability at the time of mission**
- **Study also intended as a design input to the exoplanet community to help formulate ideas for the next Decadal Survey**



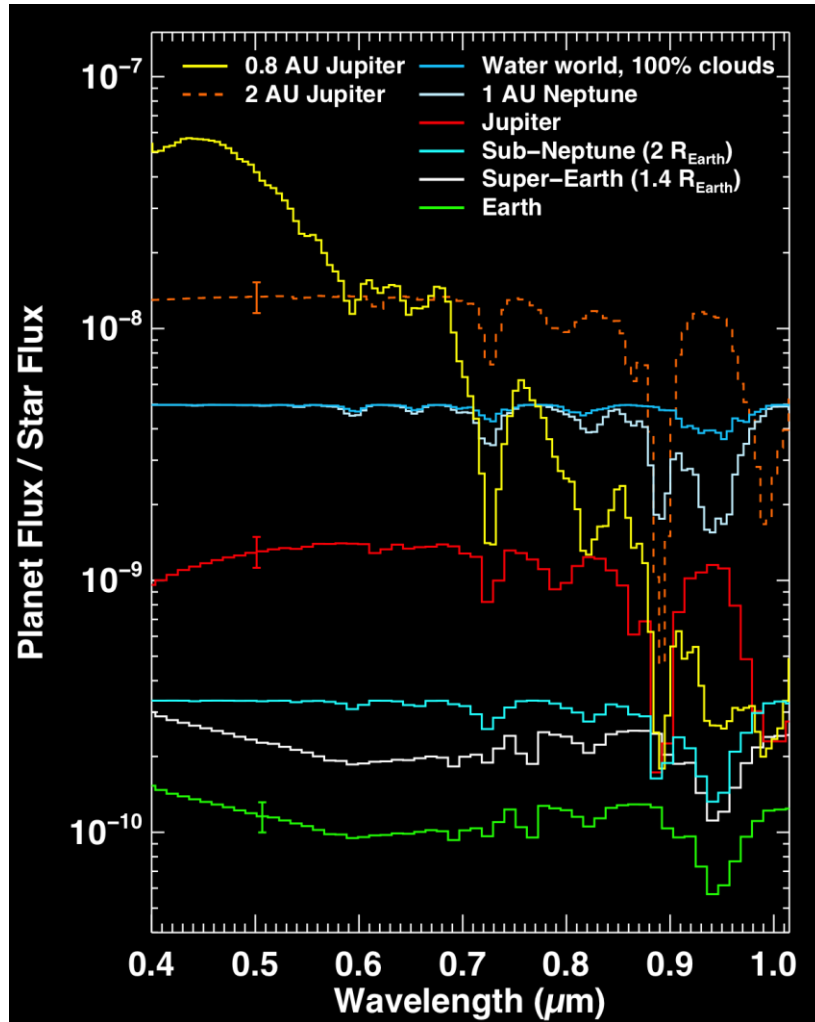
- **Contrast and IWA decoupled from telescope aperture size**
- **No outer working angle**
- **High throughput, broad wavelength bandpass**
- **High quality telescope not required**
  - Wavefront correction unnecessary
- **Retargeting requires long starshade slews (days to weeks)**

# Two Cost Constrained Exo-S Concepts

- **Exo-S Dedicated Co-Launched Mission**
  - Starshade and telescope launch together to conserve cost
  - Telescope: low-cost commercial Earth observer, 1.1 m diameter aperture
  - Starshade: 30 m diameter
  - Orbit: heliocentric, Earth-leading, Earth-drift away
  - Retargeting: by the telescope spacecraft with solar-electric propulsion
  - Three year Class B mission
- **Exo-S Rendezvous Mission**
  - Starshade launches for a rendezvous with an existing telescope
  - Telescope: WFIRST/AFTA 2.4 m is adopted
  - Starshade: 34 m diameter
  - Orbit: Earth-Sun L2 (assumption for the purposes of the Exo-S study)
  - Retargeting: by the starshade spacecraft with chemical propulsion
  - Three year Class C mission
  - Minimal impact to current mission design
    - No stringent requirements are imposed on the WFIRST/AFTA spacecraft
    - No new instrument, only modification to the existing coronagraph



# Exo-S Science Goals



1. Discover new exoplanets from giants down to Earth size
2. Characterize new planets with R=10 to 70 spectra
3. Characterize known giant planets with R=70 spectra and constrain masses
4. Study planetary systems including circumstellar dust
  - Locate dust parent bodies
  - Evidence of unseen planets
  - Exozodi assessment for future missions



# DRM Yield Summaries

Completeness			
	Case 1	Case 2	Case 3
HZ Earth	6.3	3.6	10.9
Earth	1.7	2.1	3.7
Sup. Earth	14.9	10.6	27.3
Sub-Neptune	30.3	26.8	52.3
Neptune	43.0	42.7	71.1
Jupiter	63.2	64.4	93.9
Total	159.5	150.2	259.2
Mean Planet Yields			
	Case 1	Case 2	Case 3
HZ Earth	1.0	0.6	1.7
Earth	0.3	0.3	0.6
Super Earth	1.5	1.1	2.7
SubNeptune	3.0	2.7	5.2
Neptune	4.3	4.3	7.1
Jupiter	6.3	6.4	9.4
Known Jupiters	14	14	12
Total	30.4	29.4	38.8

## Large Planet Characterization

Number of Targets		Case 1	Case 2	Case 3
Jupiter	R > 20	13	25	29
	R = 70	10	24	19
Sub-Neptune	R > 20	0	24	13
	R = 70	0	0	1

Completeness is the probability of detecting planet if it's there, summed over all stars

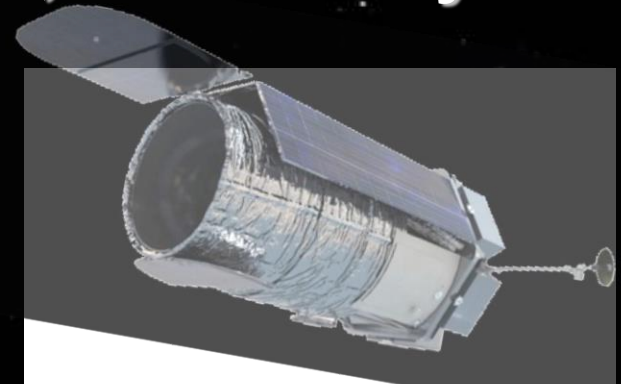
Multiply completeness by planet frequency ( $\eta$ ) to get expected yield

**Assumed  $\eta = 16\%$  for Earths,  $\eta = 10\%$  for all other planets**

Number of stars for which R=X spectra of Jupiters and sub-Neptunes can be acquired

# **WFIRST/AFTA can be leveraged for a unique and timely opportunity**

- Rendezvous Mission can access up to 50 unique target stars for exoEarths in the habitable zone**
- Minimal modification needed for starshade readiness**
- Starshade technology is on track for TRL-5 by 2017 and for new start by 2018, but not fully funded**
- Mission cost ~ \$627M**

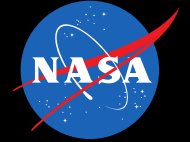


# Cost Estimates

- **Cost estimates from Exo-S Team, JPL Team X, and Aerospace CATE**
- **Dedicated mission went slightly over \$1B cap**
- **Rendezvous mission Phase A – F cost: \$627M**

*The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and Caltech.*

# Exo-C coronagraph probe mission study



**Michael McElwain, on behalf of the  
Science & Technology Definition Team:**

**Karl Stapelfeldt (NASA/GSFC, Chair);  
Rus Belikov & Mark Marley (NASA/Ames);  
Geoff Bryden, Gene Serabyn, & John Trauger  
(JPL/Caltech); Kerri Cahoy (MIT);  
Supriya Chakrabarti (UMass Lowell);  
Michael McElwain (NASA/GSFC);  
Vikki Meadows (U of Washington)**

**JPL Engineering Design Team:**

**Frank Dekens (lead), Keith Warfield, Michael  
Brenner, Paul Brugarolas, Serge Dubovitsky,  
Bobby Effinger, Casey Heeg, Brian Hirsch,  
Andy Kissil, John Krist, Jared Lang, Joel  
Nissen, Jeff Oseas, Chris Pong, Eric Sunada**

**NASA Exoplanet Program Office:**

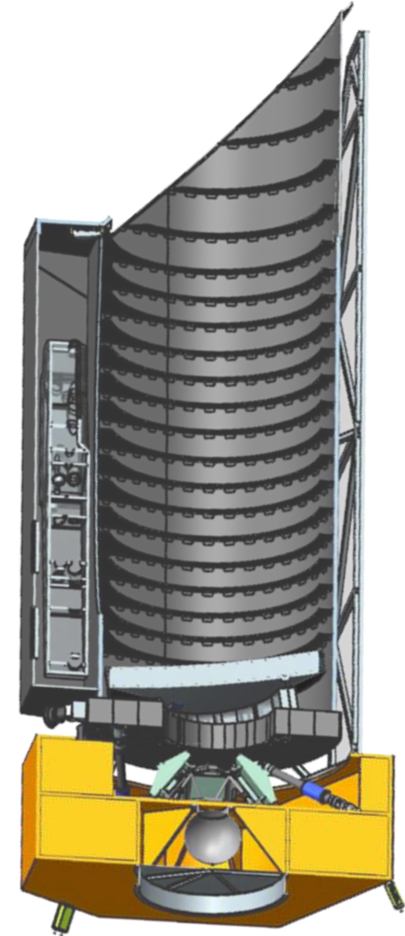
**Gary Blackwood, Steve Unwin**



# Exo-C Report Findings

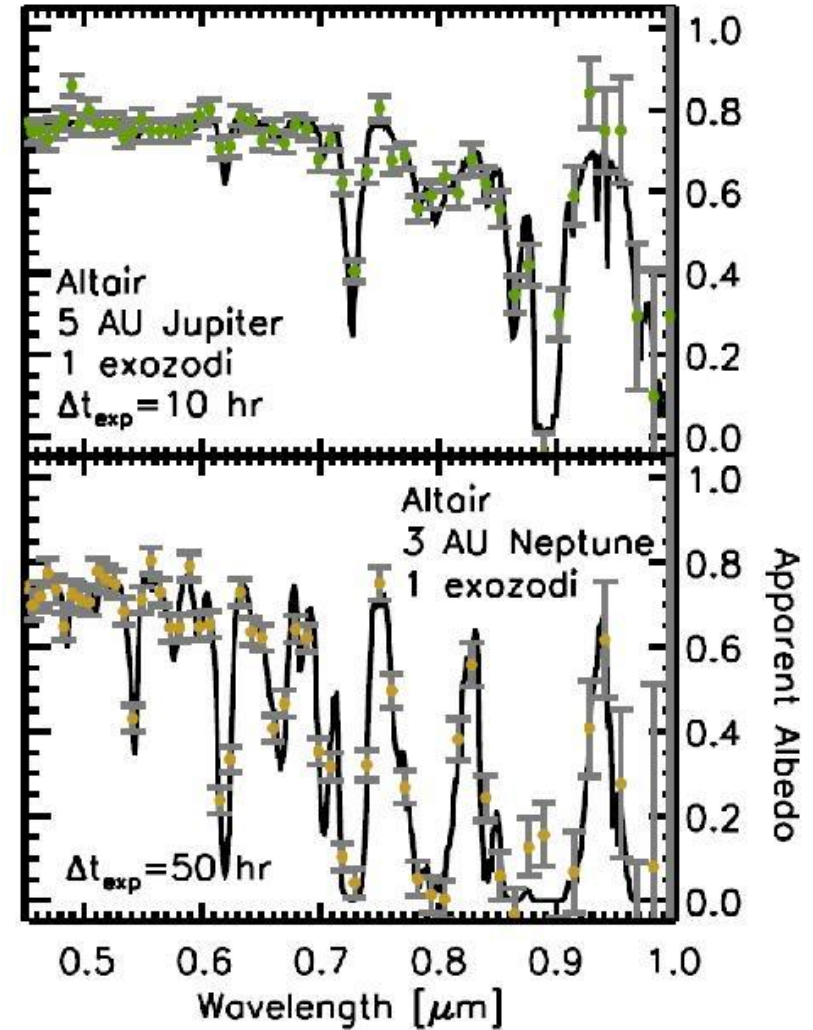
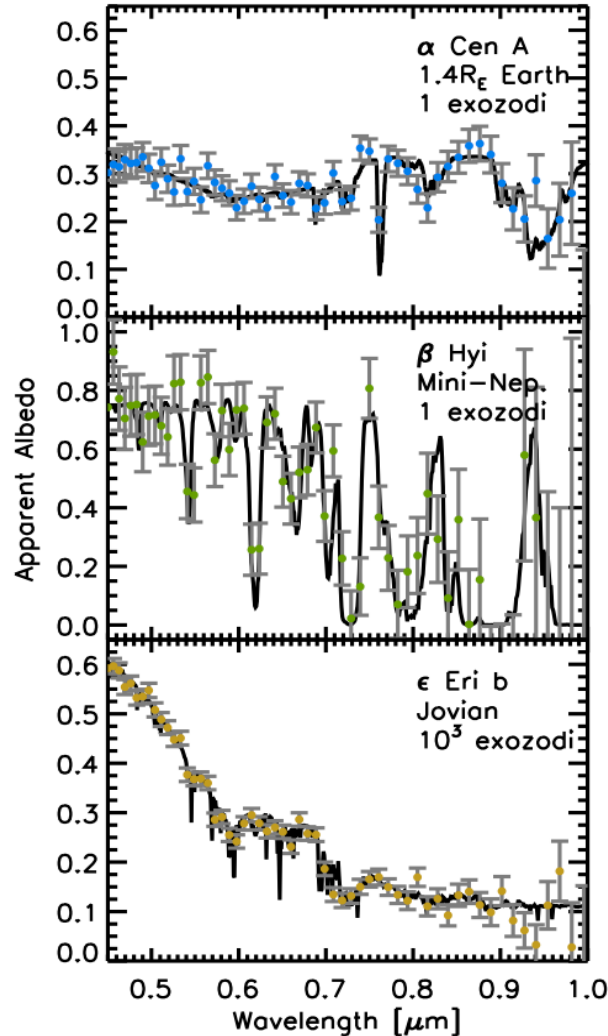


- Exo-C uses an internal coronagraph with precision wavefront control to conduct high contrast imaging at visible wavelengths
- Exo-C's science goals are to:
  - Spectrally characterize at least a dozen RV planets
  - Search >100 nearby stars at multiple epochs for planets down to  $\sim 3 \times 10^{-10}$  contrast. Characterize mini-Neptunes, search the  $\alpha$  Centauri system.
  - Image hundreds of circumstellar disks
- Even though coronagraph missions have been studied for 20 yrs, engineering designs evolved significantly to improve performance and risk (cost).
- Exo-C internal costs estimate is \$950 M, independent cost estimate is only slightly higher. Study has met its goal of achieving mission with cap of  $\sim$ \$ 1B.





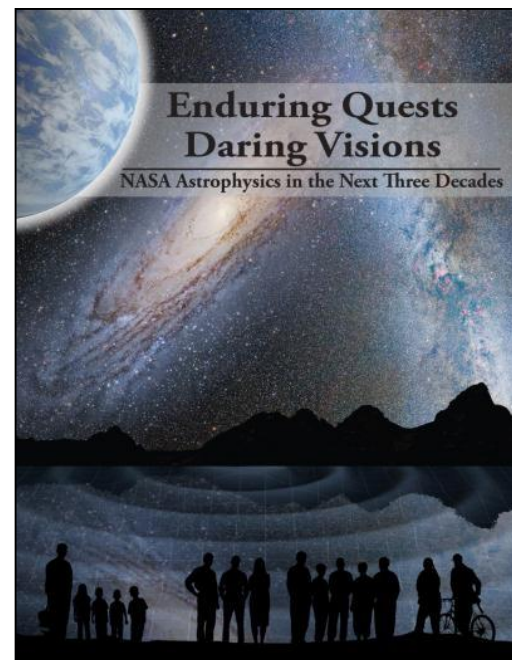
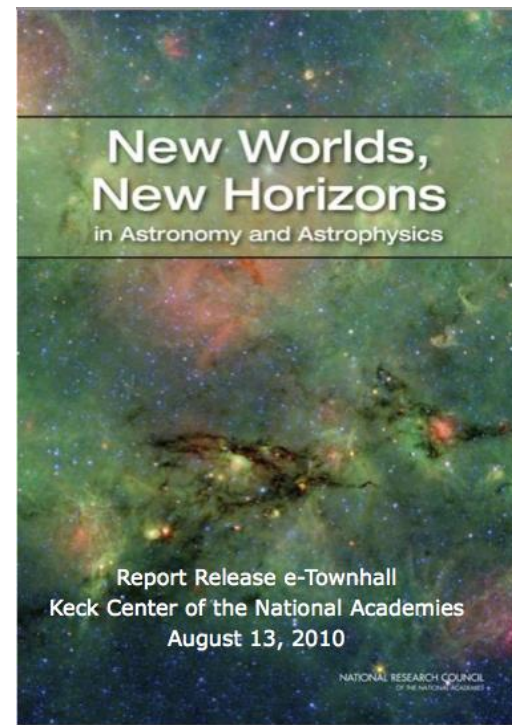
# Exo-C Simulated Spectroscopy



Work by Ty Robinson (ORAU / NASA Ames)

# Hertz's Charge to the PAGs.

“I am charging the Astrophysics PAGs to solicit community input for the purpose of commenting on the small set [of large mission concepts to study], including adding or subtracting large mission concepts.”



# **Far-IR Surveyor (EQDV)**

- **Far-IR Surveyor, architecture TBD**
  - **A) 4-6m filled aperture, single-dish, cold**
  - **B) 10m+ segmented**
  - **C) 10m+ equivalent interferometric system**
  - **Imagers, spectrographs**



# **LUVOIR (EQDV)**

- **Large UVOIR Surveyor**
  - 8-16m (likely segmented, obscured primary)
  - HST-like bandpass (91nm – ~2 microns)
  - Suite of imagers/spectrographs
  - Need  $\sim 10^{-10}$  contrast for planet imaging (coronagraph and/or starshade), less contrast for other studies

# **X-ray Surveyor (EQDV)**

- **X-ray Surveyor**
  - Angular resolution better than 1''
  - 3 sq. m effective area
  - High-resolution spectroscopy (few thousand) over a broad band
  - FOV ~ 5'
  - Wavelength range ~0.1-10 kev

# **Habitable Exoplanet Finder (NWNH)**

- **HabEX**
  - 4-8m monolith
  - Needs  $\sim 10^{-10}$  contrast
  - Coronagraph, wavelength of 0.5-1.0 micron
  - And/or starshade, wavelength of 0.25-1.0 micron
  - Camera
  - IFU, R=70 spectrum of 30m exoplanet
  - 1" FOV
  - Optimized for exoplanets, but other uses of instruments possible
  - L2 orbit or Earth-trailing

# **ExoPAG's Plans to Respond to Paul's "Large Mission" Charge.**

- The ExoPAG had already initiated the process of building consensus for an "Exoplanet Roadmap" through the SIG #1 activities.**
- The ExoPAG has and will continue to respond to Paul's charge under the auspices of this SIG.**

# **SIG #1: Toward a Near-Term Exoplanet Community Plan.**

**The goal of this Science Interest Group is to begin the process of developing a holistic, broad, unified, and coherent plan for exoplanet exploration, focusing on areas where NASA can contribute. To accomplish this goal, the SIG will work with the ExoPAG to collect community input on the objectives and priorities for the study of exoplanets. Using this input, it will attempt develop a near term (5-10 year) plan for exoplanets, based on the broadest possible community consensus. The results of this effort will serve as input to more formal strategic planning activities that we expect will be initiated after the mid-decadal review, in advance of the next decadal survey.**

**Introductions at ExoPAG 8+9, sessions at ExoPAG 10 + 11, one stand alone meeting (February 10+12, 2015).**

# **COPAG's Plans to Respond to Paul's "Large Mission" Charge.**

- **Bi-weekly COPAG telecons**
- **Joint PAG Executive Committee telecon on February 24**
  - Began cross-PAG discussions of approach to responses, cooperation
- **COPAG call for white papers released on March 2**
- **COPAG virtual town hall on March 10**
  - Outlined charge from Paul Hertz and COPAG call for white papers
  - Explained what COPAG will / will not do in response to charge
  - Questions / clarifications
  - 60-70 attendees via webex, 40-50 attendees on the phone
  - Charts are appended in Backup Slides (slides 51-62)
  - A second VTH is planned for May 2015 to discuss community inputs
- **Joint PAG Executive Committee meeting at STScl on March 19**
  - Agenda topics on next page
  - Webex available for offsite EC / Program Office / HQ personnel

# **PhysPAG's Plans to Respond to Paul's "Large Mission" Charge.**

- **March**
  - SIGs have started collecting community input
  - Develop list of questions and issues the PhysPAG wants to address in its report
- **April - June**
  - Community input phase
  - Parallel work on PhysPAG report outline
  - Parallel joint PAG meetings
- **July – September**
  - Write PhysPAG report
  - Coordinate PhysPAG report with other PAGs

# **Joint PAG Executive Committee Meeting**

**March 19**

**Meeting Slides**



# Upcoming Meetings

- **April 11-14, Am. Phys. Soc. (Baltimore) - PhysPAG**
  - SIGs and PCOS mini-symposium
- **Early May – Virtual Town Hall – COPAG**
- **\*May/June – Virtual Town Hall (2 hour) – Joint PAG**
  - Specific questions to be drafted
- **\*June 3-5, Far-IR Workshop (Caltech) – COPAG**
- **\*Late June, UV/Optical Workshop (TBD) – COPAG**
- **\*June 13-14, ExoPAG #12 (Chicago) - ExoPAG**
  - Half to full day to be spent on charge (2<sup>nd</sup> day)
- **\*June 29-July 1, HEAD (Chicago) – PhysPAG**
  - Need to register for HEAD meeting, but don't need to be member
- **August 3-14, IAU, (Honolulu) – Joint PAG (chairs + overview)**
  - FM11, FM14, or others (present status rather than ask for input)
  - Special session or splinter meeting? (June 15 deadline)
- **August, Virtual Town Hall – Joint PAG**
  - Chance to present overview of report to community

**\*PAG reports related to charge**

# Probes?

- **Should be part of process of planning for next decadal survey.**
  - **Could be done outside of this particular flagship process.**
- **Need to have NASA define probes.**
- **Need to understand costing of probes.**
- **Do probes need mission-funded technology development?**

One of the fastest-growing and most exciting fields in astrophysics is the study of planets beyond our solar system. The ultimate goal is to image rocky planets that lie in the habitable zone—at a distance from their central star where water can exist in liquid form—and to characterize their atmospheres. To prepare for this endeavor, the committee recommends a program to lay the technical and scientific foundations for a future space imaging and spectroscopy mission. NWNH - page 250

If progress is sufficiently rapid by mid-decade, then a decadal survey implementation advisory committee (as discussed in Chapter 3) could determine whether a more aggressive program of technology development should be undertaken, possibly including steps toward a technology down-select and a focus on key elements. Either way, decisions on significant, mission-specific funding of a major space mission should be deferred until the 2020 decadal survey, by which time the scientific path forward should be well determined. NWNH – page 230